Dowler J. Thomson

"SCHOOL HELPS" SERIES

Astronomical and Mathematical Geography

BY

M. PARKINSON

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ASTRONOMICAL AND MATHEMATICAL GEOGRAPHY

BY

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PREFACE.

THIS little manual is a condensed statement of the chief facts in Astronomical and Mathematical Geography, so far as they should be known to the pupils of our Public and High Schools.

The teachers of Entrance and Leaving Classes in the Public Schools, and of Form I. Classes in the High Schools will find, brought within the compass of its one hundred pages, all the information necessary to place these subjects intelligently before their pupils. At the same time the book has been written in such a simple style that it is believed every pupil will easily understand each of its sections, and, with the volume in hand, readily prepare the work in this department of Geography for himself.

The author puts forward no claim to originality. The collecting, classifying and simplifying of Astronomical and Mathematical facts in relation to the subject of Geography has been his object ; and no excuse for publishing such a work could be given if we had had in the market an inexpensive, comprehensive and trustworthy volume treating on such matters.

The author would refer his readers to the following

works for a fuller treatment of the subject; and at the same time would acknowledge his own indebtedness to them:

A NEW ASTRONOMY.—American Book Company.

ECLECTIC PHYSICAL GEOGRAPHY.—American Book Company.

JACKSON'S ASTRONOMICAL GEOGRAPHY.—D. C. Heath & Company.

STEELE'S DESCRIPTIVE ASTRONOMY.—American Book Company.

THIS WORLD OF OURS.—Cassell & Company.

The illustrations have been largely copied from the above works, but in every case acknowledgment has been made of the fact.

M. PARKINSON.

TORONTO, March, 1899.

D Walter Thomson

PART I.

THE HEAVENLY BODIES

CHAPTER I.

I.—THE SOLAR SYSTEM.

1. **The Solar System** consists of the following bodies :—

1. *The Sun*—the centre.
2. *The Major Planets*—Vulcan (?), Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus (ū′-ra-nŭs), Neptune.
3. *The Minor Planets*, or asteroids, at present (1899) five hundred in number.
4. *The Satellites*, or moons, twenty-one in number, which revolve around the different planets.
5. *Meteors* and shooting-stars.
6. *Thirteen Comets*, which have now been found, by a second return, to move, like the planets, in elliptic paths, and to revisit the sun periodically.
7. *The Zodiacal (zo-dī′-a-cal) Light.*

We are to imagine these bodies as suspended in space, held together by the law of gravitation, whereby each planet attracts every other planet and is in turn attracted by all.

In the midst is that great central globe—the sun. So vast is he that he can overcome the attraction of

The Sun and his Family.

all the planets, and compel them to circle round him. Then come the planets, each turning on its axis while

it flies around the sun in an elliptical orbit. Then there are the satellites, or moons, each again rotating on its own axis, and at the same time revolving around its parent planet, while all whirl in a dizzy waltz around the great central orb. Last of all come the comets, rushing across the planetary orbits at irregular intervals of time and space; and the meteors and shooting-stars, darting hither and thither, interweaving all in apparently inextricable confusion.

The foregoing diagram will help to more thoroughly understand the Solar System. It shows all the planets, their relative size, their distances from the sun, and the satellites of each.

II.—THE SUN.

1. The Sun's Distance.—The average distance of the earth from the sun is 93,000,000 miles. But as the orbit of the earth is an ellipse, and the sun is situated in one of its foci, we are 3,000,000 miles nearer the earth in *perihelion* (the point in the earth's orbit nearest the sun) than in *aphelion* (the point in the earth's orbit farthest from the sun).

This distance is entirely beyond our grasp; but we may get some conception of it if we consider the following:—

(*a*) An express train travelling day and night at the rate of thirty miles per hour would require 352 years to reach the sun. If Shakespeare had started on this excursion on the day of his birth he would not yet be at the end of his journey.

(*b*) If a child were born with an arm long enough to reach the sun, and should touch that fiery globe, the infant would grow to manhood, and finally reach old age and die, before the sensation could traverse the nerve to his brain and he feel the burn.

2. **The Sun's Size.**—The size of the sun is also entirely beyond our comprehension. To say that the sun is 865,350 miles in diameter gives us no conception whatever of its size. The following illustrations may give a slight idea of its vastness :—

(*a*) If we should conceive for a moment the sun as a hollow sphere with the earth placed at its centre, and the moon revolving around the earth at its present distance, then the outer crust or rim of the sun would still be 190,000 miles from the moon.

(*b*) The hollow sun would require 1,300,000 worlds such as ours to fill its cavity.

(*c*) The mass of the sun is 750 times that of all the planets along with their moons.

(*d*) An athlete who could jump 6½ feet from the ground on the earth would find that when transferred to the sun his highest jump could not exceed three inches.

3. **The Sun's Light.**—The light of the sun is equal in brilliancy to the combined power of 5,563 wax-candles held at a distance of one foot from the eye. The amount of light received from the sun is equal to that from 600,000 full moons.

4. **The Sun's Heat.**—The heat of the sun is again entirely beyond our comprehension. We may

form some conception of the sun's heat from the amount of heat received by the earth from the sun. The heat falling on five feet square of the earth's surface would produce sufficient energy to do the work of five men. If the heat falling on the deck of a steamer in the tropical ocean could be utilized, it would be sufficient to propel it at about ten knots an hour. But, when we consider that the intensity of heat decreases as the square of the distance from the radiating body increases, we find that the amount of heat radiated by a given area of the sun's surface must be about 46,000 times greater than that received by an equal area on the earth. The sun emits sufficient heat in one second to melt a solid cylinder of ice three miles in diameter, reaching from the earth to the sun.

The question of "how the sun's heat is maintained" has occupied the minds of scientific men for centuries. Two theories have been advanced:—

(1) Helmholtz, an eminent German physicist, proposed the theory that the sun's heat was produced by condensation of the sun itself, thus constantly changing its potential energy into kinetic energy. So enormous is the volume of the sun that an actual shortening of its diameter by six miles in a century would fully account for all the heat which it gives out.

(2) Another theory accounts for the heat of the sun by assuming that there are vast numbers of meteors revolving round the sun and constantly raining down on its surface. This theory would necessitate an amount of matter equal to a hundreth part of the earth falling from the present distance of the earth upon the sun during each year.

5. The Physical Constitution of the Sun.—Very little is definitely known of the constitution of the sun. But it is generally supposed to be a vast, fiery body, surrounded by an atmosphere of substances volatilized by the intense heat. The different portions of the sun are spoken of as follows :—

(*a*) The *nucleus*, probably composed of gases, in the consistency of tar or pitch, on account of the intense heat and compression due to solar gravity.

(*b*) The *photosphere*, an envelope several thousand miles thick, which radiates the light of the sun.

(*c*) The *chromosphere* ; this envelope, composed chiefly of hydrogen, surrounds the sun to a depth of from 5,000 to 10,000 miles. Tongues of fire from 100,000 to 350,000 miles in length shoot up through this chromosphere at the rate of 150 miles per second.

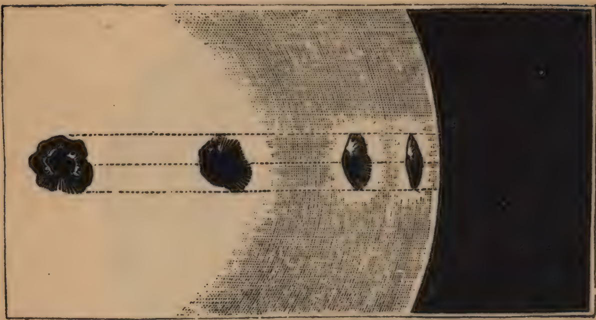
(*d*) The *corona* ; this is the outer appendage of faint, pearly light. Very little is known about it, because it can only be seen during total eclipses of the sun.

6. Sun Spots.—Sometimes the sun's disc, as seen through a telescope, is clear. Sometimes as many as 200 irregular spots are seen to sprinkle its surface. Probably some of these spots are deep openings in the atmospheres of the sun. And when we consider that some have reached a diameter of 150,000 miles and occupied $\frac{1}{35}$ of the whole surface of the sun, we may have some conception of what abysses they must be, at "the bottom of which our earth would be like a boulder in the crater of a volcano."

Sun Spot, highly magnified (after Secchi).

When sun spots are most numerous, the earth is visited by severe magnetic storms. Telegraph messages may be sent many hundreds of miles without the aid of the batteries. At these times displays of aurora borealis are most frequent and brilliant. No explanation has, as yet, been given for these coincidences.

7. The Sun's Rotation on its Axis.—The rotation of the sun on its axis is proved by the passage of a sun spot across its face. An oval spot which appears on the eastern side of the sun widens and becomes circular as it faces the earth more squarely on approaching the centre, and having passed that point it gradually narrows again until it passes off the western limit of the sun an oval spot as it was first seen. The following illustration shows how this takes place.



Change in Spots as they cross the Sun's Disc (after Steele).

The sun's period of rotation, as referred to the stars, is 25¼ days, but as the earth is moving on in its path eastward around the sun, it takes the sun 27½ days to acquire the same position relative to the earth.

III.—THE MAJOR PLANETS.

Tethered by an overmastering attraction to the central and massive orb of the solar system are a multitude of bodies classified as planets. Next to the moon they are the nearest heavenly bodies. Because of this, we know more concerning them than we do of the other heavenly spheres.

If you watch the heavens for some length of time, you will notice that nearly all the bright stars do not change their position with reference to each other; but at nearly all times you may notice one or two bright stars which slowly shift their positions from

week to week. These apparent motions were known to the ancients, who gave to such bodies the name planets; that is, wanderers.

1. **Common Characteristics.**—All the planets have many characteristics in common. These points of resemblance led astronomers to look for a common origin of all the bodies composing our Solar System. Such an explanation is found in the Nebular Hypothesis, which will be fully set forth in our Physical Geography.

1. All the planets move round the sun from west to east.
2. They all move in elliptical paths.
3. Their orbits are all more or less inclined to the ecliptic.
4. They are all opaque bodies, and shine by reflecting the light they receive from the sun
5. They all rotate on their axis from west to east.
6. Acting under gravity, their velocity is quickest at *perihelion* and slowest at *aphelion*.

We shall now proceed to describe the planets in order, passing from the sun outward.

VULCAN.

The existence of a dark planet inside the orbit of Mercury (see diagram, page 6) has been affirmed by both American and European astronomers; but, as yet, its existence is not generally conceded. The name Vulcan has been given to it. Its distance from the sun has been estimated at 13,000,000 miles, and its periodic time (its year) at twenty days.

MERCURY.

Mercury is the nearest to the sun of the definitely-known planets. When the sky is clear we may see it near the western horizon after sunset in spring, or near the eastern horizon before sunrise in autumn. It is of a pale ash color, and may be distinguished by its violent twinkling.

Mercury's mean distance from the sun is 36,000,000 of miles. The eccentricity of its orbit is very great, the planet being 15,000,000 of miles nearer the sun at perihelion than at aphelion. Its sidereal revolution (measured from a fixed star) is 88 days, while its synodic revolution (measured from the earth) is 116 days. The reason for this is that when Mercury comes round again to the same fixed star, and has therefore completed a sidereal (*sidus*, a star) period, the earth has moved on eastward in its orbit, and Mercury requires 28 days to overtake it. It rotates on its axis in the same time that it revolves around the sun, thus making its year and its day of the same length.

Mercury is 3,000 miles in diameter. It would require 20 globes as large as Mercury to make the earth, or 25,000,000 to make the sun. It is $\frac{1}{5}$ denser than the earth and its mass is nearly $\frac{1}{16}$ of our globe. A man who weighs 160 pounds on the earth would weigh only 70 pounds on the surface of Mercury.

The axis of Mercury is inclined at an angle of 70° from the perpendicular. The result is that there can be no fixed zones as there are on the earth, but at one time the sun pours down its vertical rays, producing a burning heat, and a few weeks afterwards sinks below the horizon, producing a night of arctic cold. The great eccentricity of Mercury's orbit tends to

increase this excessive heat and excessive cold. At perihelion the sun's heat is ten times as great as ours, and the average heat is about seven times—a temperature sufficient to turn water into steam.

The planet presents, when viewed through the telescope, all the phases of the moon. We never see it when full or nearest the earth, and therefore the brightest, as then its dark side is turned toward us.

VENUS.

Venus, excepting the sun and moon, the brightest object in the sky, is known to everybody. She is of a brilliant straw color, and during her period of greatest brilliancy is sometimes seen with the naked eye in full daylight. She may be seen easterly in the early morning or westerly after sunset, and as she is so much brighter than any other of the planets she cannot be mistaken.

The orbit of Venus is nearly circular; her mean distance from the sun is 67,200,000 of miles, which varies at aphelion and perihelion by 1,000,000 miles. Her sidereal period is 225 days; her synodic period 584 days. Like Mercury, Venus turns once on her axis while going once round the sun; her solar day, therefore, never ends, and her sidereal year and sidereal day are equal in length.

The diameter of Venus is 7,700 miles; her volume and density are each about $\frac{9}{10}$ that of the earth. A man weighing 160 pounds on the earth would weigh only 140 pounds on the surface of Venus.

The axis of Venus is inclined at an angle of 75° from the perpendicular, thus her torrid zone is 150° in width, and her torrid and frigid zones interlap through a space of 60°. Thus Venus must have an

excessive climate similar to that of Mercury. Venus, like Mercury, has its orbit within that of the earth, and therefore presents all the phases of the moon.

MARS.

The planet Mars most resembles the earth. In color it is reddish ochre; it shines with a steady light and is easily distinguished by its red appearance. At intervals of nearly 15 years Mars comes into apposition with the sun when the planet is in perihelion and the earth in aphelion, and it then shines with a brilliancy rivalling that of Jupiter himself.

The mean distance of Mars from the sun is 141,500,000 miles. It is 26,000,000 of miles nearer the sun in perihelion than in aphelion. Her sidereal period is 687 days and her synodic period 780 days. The Martian day is 24 hrs. 37 min. 22.7 sec.

The diameter of Mars is 4,200 miles. Its volume is about $\frac{1}{7}$ and its density $\frac{4}{5}$ that of the earth. A man weighing 160 pounds on the earth would weigh 60 pounds on the surface of Mars.

The axis of Mars is inclined at an angle of 27° from the perpendicular; therefore its zones and seasons would be somewhat similar to our own. You will notice its day is about the same length, its year is nearly twice as long, therefore its seasons would be twice ours in length. Mars, more than any other of the planets, presents the conditions of an habitable world.

Mars has two moons, discovered in August, 1877. They are about seven miles in diameter and can be seen only by large telescopes under favorable conditions.

JUPITER.

Jupiter is the largest of the planets. Next to Venus it is the brighest of the planets and is much brighter than any fixed star. Jupiter has a bright silver color and is readily distinguished from a star by the absence of twinkling.

Jupiter revolves around the sun at an average distance of 483,333,333 miles. The eccentricity of its orbit is 47,000,000 of miles. Jupiter's sidereal year is 11⅞ of our years, while its synodic period is 399 days. Jupiter revolves on its axis in 9 hrs. 55½ min., therefore it takes this planet nearly 10,000 of its own days to revolve around the sun.

The diameter of Jupiter is 87,000 miles. This gives it a volume 1,400 times that of the earth, or much greater than that of all the other planets. A man weighing 160 pounds on the earth would weigh 420 pounds on the surface of Jupiter.

The axis of Jupiter is only slightly inclined, therefore the days and nights are about equal in length, or of about five hours each. The seasons are but slightly varied, at the poles the sun is visible for nearly six years.

Jupiter has five moons. The fifth or innermost was discovered by Barnard in 1892. The evening sky as presented to a Jovian must be a magnificent spectacle. Not only does he see the glittering stars which adorn our heavens, but these five moons, waxing and waning, each with its own phase, illuminate his night. And all this splendid panorama sweeps through his sky in five hours. It is probable that Jupiter has no solid crust but consists of molten matter surrounded by vapor that continually rises from the heated interior.

SATURN.

This was the most remote planet known to the ancients. He shines with a dull yellow light, which distinguishes him from the fixed stars. Saturn is difficult to find because he shines with about the order of brightness of a star of the first magnitude.

His mean distance from the sun is 886,000,000 of miles. At perihelion he comes 90,000,000 of miles nearer the sun than at aphelion. His sidereal period is 29½ years and his synodic period is 378 days. The Saturnian days are each 10 hrs. 12 min. 53 sec. in length.

The diameter of Saturn is 71,000 of miles. His volume is therefore about 700 times that of the earth; but, as his density is only about ¾ that of water or ⅛ that of the earth, his mass is very little greater than the mass of the earth. A man weighing 160 pounds on the earth would weigh 170 pounds on the surface of Saturn.

Saturn receives from the sun about $\frac{1}{100}$ of the light and heat which we receive. His axis is inclined about 31° degrees from the perpendicular; therefore, his seasons closely resemble those of the earth. But when we remember that his year is 29½ times the length of ours we will at once see that each of his seasons will last more than seven of our years. For almost fifteen years the sun shines continuously on his north pole.

Surrounding Saturn are three rings of enormous size, the outer ring having a diameter of 173,000 miles, a width of 11,500 miles and a thickness of 100 miles. These rings revolve around Saturn in the same direction as the planet rotates on its axis. The rings are neither solid nor liquid, but are composed

of enormous clouds or shoals of very small bodies—too small to be seen with the telescope—travelling round the planet, each in an orbit of its own, as if a satellite. It is highly probable that the ring system is a ninth satellite in process of formation. (See Nebular Hypothesis in our Physical Geography.)

Saturn's Rings.

Saturn has eight moons. The largest, Titan, exceeds Mercury in size. The magnificence of a Saturnian night can be imagined, but never described. The rings form an immense arch, spanning the sky and shedding forth a soft radiance, while the eight moons in all their phases—full moons, new moons, crescent moons and gibbous moons—add to the strange beauty of the scene. Saturn, like Jupiter, has no solid crust, but is composed of molten matter not yet solidified. Jupiter and Saturn are older than the earth, but because of their great size they have cooled more slowly, and, in consequence, are as yet only partially solidified. They now are in the same condition as the earth was long ages ago before a solid crust had been formed upon its surface.

URANUS.

This planet is just on the limit of visibility without the aid of a telescope. It may be seen during the spring and summer months, if one has a keen eye and knows just where to look. It was discovered by Sir William Herschel on the 13th of March, 1781.

Uranus (ū'-ra-nŭs) revolves around the sun at a mean distance of 1,780,000,000 of miles. At perihelion Uranus approaches 166,000,000 of miles nearer the sun than at aphelion. The sidereal year of Uranus is 84 of our years and its synodic period is 370 days. Its rotation on its axis probably occupies about 10½ hours.

The diameter of Uranus is 31,700 miles. Its density is about ¼ that of the earth. A man weighing 160 pounds on the earth would weigh 144 pounds on the surface of Uranus.

Little is known regarding the seasons on Uranus. The sun light on the planet would be about equal to that of three hundred full moons.

Uranus has four satellites. Only the largest telescopes will show them. They revolve in planes nearly at right angles to the planet's orbit, and their motion is from east to west. This seeming contradiction of the Nebular Hypothesis is as yet a puzzle to astronomers.

NEPTUNE.

Neptune is the far-off sentinel watching the regions of space outside the solar system. It is invisible to the naked eye and appears in the telescope as a star of the sixth magnitude.

The discovery of this planet must ever stand as one of the grandest achievements of the human

mind. Early in the present century it was found that Uranus was straying widely from his theoretic position. For a long time the cause of these perturbations remained a mystery, but at length it was suggested that there was another planet exterior to Uranus whose attraction caused this deviation.

Two young astronomers, Adams in England, and Le Verrier in France, undertook to find this undiscovered planet. They knew the disturbance produced by the attraction of the planet, and from this they set out to find its orbit and its place in the orbit. After two years of hard labor Adams laid his results before the English astronomers and the result was that Neptune was discovered. Le Verrier sent his results to the Berlin observatory, and the astronomer, Dr. Galle, turned his telescope to the place indicated and immediatelly detected a bright star not laid down in the maps, which proved to be the planet sought for, found within a degree of the spot described by Le Verrier.

Neptune is 2,790,000,000 of miles from the sun. The Neptunian year is equal to 165 terrestrial years. Its diameter is 34,500 miles, and its density about $\frac{1}{8}$ of that of the earth. Nothing is definitely known of its axial rotation or of its seasons.

Neptune has one moon, which is placed at about the same distance from the parent planet as our moon is from us. It revolves around Neptune every six days.

We have now reached the outmost limit of our solar system. Still we are no nearer the boundaries of space, no nearer the limit of God's universe. On Neptune, the same heavens bend above us; the Milky Way is no nearer to the eye; the fixed stars

are still mere glittering points of light in the far-off sky.

Then, here we may stand on this far-away orb and look out upon the immensity of the systems still beyond us, of which each twinkling star is a parent sun, and form at least some slight conception of the greatness of Him who is Author of all, and who holds these magnificent worlds and systems in the hollow of His hands.

IV.—THE MINOR PLANETS.

Between Mars, 141,500,000 miles from the sun, and Jupiter, 483,333.333 miles from the same orb, there is a wide interval of space that was not filled until the present century. J. E. Bode (bō'dŭh), in the latter part of the eighteenth century, promulgated a law which approximately represented the relative distances of the planets from the sun. It was derived in this way. Write this simple series of numbers, in which each, except the second, is double the one before it :—

0, 3, 6, 12, 24, 48, 96, 192.

Add 4 to each,

giving 4, 7, 10, 16, 28, 52, 100, 196.

The actual distance of the planets in millions of miles is, as we have shown :—

36, $67\frac{1}{5}$, 93, $114\frac{1}{2}$; small planets, $483\frac{1}{3}$, 886, 1,780.

This law, although now of no importance, directed attention to the vast break in the succession of planets between Mars and Jupiter. There was no known

planet to correspond with 28 in the series. This led to a society of 24 astronomers uniting in systematic search for the missing planet. Strange to say, Piazzi, an astronomer of Sicily, on January 1st, 1801, the opening day of the 19th century, discovered the first of these miniature worlds, quite independently of the 24 astronomers before mentioned, while searching for a star which had, by mistake, been put in Wollaston's Catalogue.

The largest asteroid, Pallas, is 300 miles in diameter; Vesta is 250; Juno 120, while the smallest cannot exceed 20 miles. Up to the present (1899) five hundred have been discovered, and probably in the near future hundreds, or possibly thousands, more will have been found. Vesta may, at favorable times, be seen without a telescope, shining as a star of the 6th magnitude. They are so small that a bicyclist might easily tour around one in a day. A prairie farmer would need to pre-empt a whole such world for a corn-field. On one of these tiny globes a man might jump over a house 60 feet in height with perfect ease.

These planetoids revolve around the sun in regular orbits, comprising a zone 100,000,000 miles in width, lying between the orbits of Mars and Jupiter. The origin of the asteroids has long been a puzzle to astronomers. The most probable explanation is that proximity to the colossal Jupiter is responsible for the existence of a multitude of small bodies, instead of one larger planet. The gravitative action of Jupiter on the matter now forming the asteroids, when it was in the form of a ring around the sun, may have precluded the possibility of the formation of a separate planet.

V.—THE SATELLITES.

The two minor planets, Mercury and Venus, have no moons. The earth has one moon. Mars has two tiny attendants. Phobos, the minor moon of Mars, is less than 4,000 miles from the planet's surface, while Deimos is rather more than 12,000. Jupiter has five moons, the fifth being discovered by Barnard in 1892. Saturn rejoices in a large family of eight distinct children, besides the wonderful rings which are undoubtedly made up of an infinity of mere babies in the planetary world. Uranus has four moons and far-away Neptune one.

VI.—METEORS AND SHOOTING-STARS.

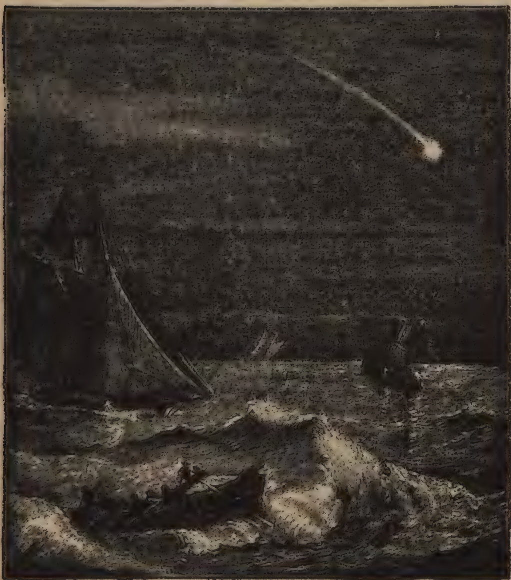
Aerolites (ā′-er-o-līts), meteors and shooting-stars are different names for particles of matter falling from space through our atmosphere.

1. Aerolites are those stony or iron masses which have from time to time fallen upon the earth. On the 10th of May, 1879, in the State of Iowa, a mass of stone weighing 437 pounds fell to the earth. The heaviest meteoric stone on record was found in Hungary in 1866. A mass of meteoric iron weighing 1,400 pounds was found in Arizona, and is now in the United States National Museum at Washington. The largest one ever seen to fall, fell in Arabia in 1865. It is now in the British Museum.

2. Meteors are luminous bodies having a spherical form. They frequently pass across the sky at night, leaving a path of glowing sparks behind them. In 1819 a meteor was seen in Massachusetts and Mary-

land, the diameter of which was estimated at half a mile. Brilliant fireballs have frequently been seen in different parts of the earth.

3. Shooting-stars are very small meteors, sometimes falling in showers. Brilliant star-showers occurred in November, 1799, and again in November, 1833. At these times shooting-stars swept over the sky like the flakes of a snowstorm. A like shower may be confidently predicted for 12th-14th November, 1899.



A Meteor with its Train.

Aerolites are easily detected wherever found, because, although they are composed of iron, tin, copper, nickel, oxygen, su phur and some fourteen other common elements, they are compounded in so peculiar a manner as to distinguish them from terrestrial substances. Meteoric iron, for example, is an alloy that has never been found among our minerals.

These meteors are now known to travel in regular orbits around the sun, and to be gathered in groups, not regularly distributed on these orbits. When the earth passes through one of these groups a star-shower follows.

All bodies of a meteoric nature are now believed to be the shattered remains of former comets. They are, of course, dark bodies. Their average velocity is 35 miles per second. The shooting-stars are probably no larger than ordinary shot, but travelling at such a great velocity they would certainly pelt us to death if it were not for the mantle of air. When these tiny particles strike our atmosphere, their velocity is checked, and the work thus done by the air is changed into heat, which fuses the exterior to incandescence. As a rule, this speedily evaporizes their entire substance, the exterior, being brushed off by the air as soon as melted, often leaves a fiery train in the sky. The body thus becomes visible to us. If small, it is consumed in the upper air. If large, it may fall to the earth as a meteorite. Their visibility begins at an altitude of 70 miles and they fade out at half that height. Prof. Young estimates that 100 tons of meteoric matter falls upon the earth each day.

VII.—COMETS.

We now come to the discussion of the most fascinating of the heavenly bodies. They were regarded by the ancients as "Fireballs flung by an angry God." They

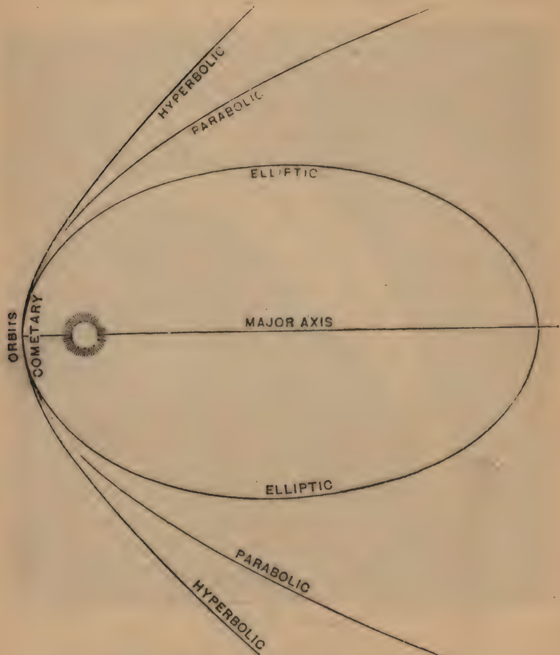
Donati's Comet.

were for centuries regarded as "signs and wonders," as a sort of celestial portent of every kind of disaster.

The comet usually consists of three parts :—

1. The *nucleus*, or bright star-like point in the centre of the head.

2. The *coma* (hair), a sort of luminous fog surrounding the nucleus.



Three Forms of Cometary Orbits.

3. The *tail*, a luminous train, stretching away into space.

Comets move around the sun in three different orbits, the *ellipse*, the *parabola* and the *hyperbola*.

A comet moving in an elliptical path around the sun will return again in a fixed time. But a comet with a parabolic or hyperbolic orbit cannot return, as the two sides separate from each other more and more. Such comets after once swinging closely around the sun, and saluting the great ruler of our system, plunge again into the unmeasured distances of space, seeking, perhaps, in the far-off void another sun, which, in turn, they will abandon as they have our own.

The origin of comets is still shrouded in mystery. Probably the comets are but chips in the work-shop of the skies—mere waste pieces of stuff that stars are made of. Between 800 and 900 comets have been observed. The next bright comet will be seen in 1910, when Halley's comet, last seen in 1835, will return.

The Great Comet of 1858.

VIII.—THE ZODIACAL LIGHT.

A faintly luminous and ill-defined triangular area may, on very clear nights just after sunset, during March and April, be observed if we watch the western horizon. The same appearance may be detected near the eastern horizon at early dawn during September and October. It is called the Zodiacal Light, and is supposed to be the mildly reflected rays of the sun from a widely diffused disc of interplanetary particles moving round the sun, interior to the orbit of Mercury, but possibly stretching out beyond the path of the earth.

CHAPTER II.

THE MOON.

1. **Motion.**—The path of the moon is an ellipse with the earth placed in one of its foci. The average or mean distance of the moon from the earth is 239,000 miles. An ordinary express train would take about a year to reach the moon. At perigee (point in the moon's orbit nearest the earth) the moon is 32,000 miles nearer the earth than it is at apogee (point in the moon's orbit farthest from the earth).

The moon completes her revolution around the starry heavens in 27 days 7 hrs. 43 min. 11.5 sec., or 27⅓ days. This is called the moon's *sidereal period*, that is, the time which is required for the moon to travel from a given fixed star eastward round to the

same fixed star again. Now, as the earth is constantly passing on in its orbit eastward around the sun, it will readily be seen that it will take some time for the moon to regain its original position with regard to the earth. It has been found that this requires over two days, so that the moon comes into the same position with respect to the sun and the earth every 29 days 12 hrs. 44 min. 2.7 sec., or 29½ days. This is the moon's synodic period, or lunar month.

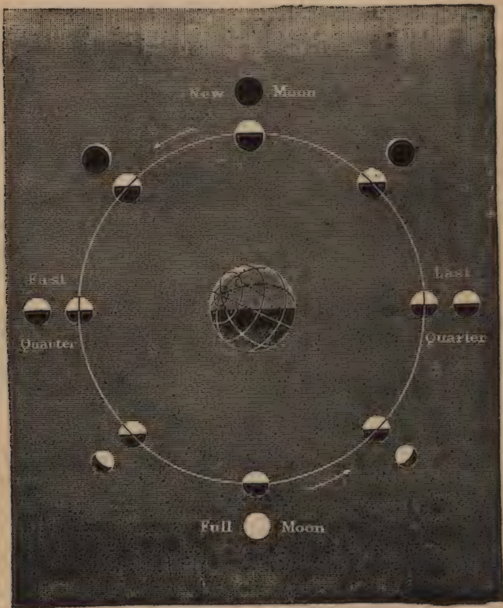
The moon rotates on her axis in the same time that she revolves around the sun. Thus the lunar day is 29½ of our days. As a result of this synchronizing of the moon's synodic period and of her period of axial rotation we can see only one side of the moon.

To illustrate this, ask a pupil to stand on the floor and request another pupil to walk around him so as not to allow the first pupil to see the back of his head. It will soon be found that the second pupil must turn once on his feet every time he walks around the first pupil.

2. Dimensions. – The moon's diameter is 2,160 miles. It would require fifty moons to make our earth. But, since the moon's density is only $\frac{3}{5}$ of the earth's density, the mass of the moon is 81 times less than the mass of the earth. A man weighing 144 pounds on the earth would weigh only 44 pounds on the moon, and he might jump 39 feet from the surface with ease.

Many think that the moon, and the sun also, are larger when near the horizon than they are when near the zenith. This is an optical delusion. The horizon appears to be more distant than the zenith because the eye, in looking toward the horizon, rests upon

many objects by the way. Therefore the moon at the horizon seems larger because the distance is apparently greater, the mind unconsciously reasoning that being so much farther away she must of course be larger in order to look the same. To dispel this illusion look at the moon through a small tube, which will shut out surrounding objects, and she will at once assume her normal proportions.



Phases of the Moon.

3. Phases of the Moon.—Sometimes we see the moon as a slender crescent in the west just after sunset. Three or four days later we see her as a half circle. Then we see her something like a football—one side circular and the other elliptical—and then again she appears as a full circle of light. These appearances of the moon—crescent, quarter, gibbous and full—represent the phases of the moon. These phases of the moon prove that she is a dark body, shining by reflecting the light she has received from the sun.

From the above cut it will be very easy to understand the cause of the moon's phases. The sun's light is supposed to come from above and illumine the upper half of the moon, as shown in the inner circle. The outer circle shows the appearance of the moon as viewed from the earth.

(1) Commencing at *new moon* and proceeding in the direction of the arrow, we first see the moon as a delicate crescent. We may see her thus in the western sky just after sunset. Her convex side will be westward, toward the sun, and her horns or cusps turned toward the east. She soon sets below the western horizon, and each succeeding evening is seen to recede farther from the sun and thus set correspondingly later. Of course we understand that half her surface is illuminated, but only a slender edge of this lit portion is turned toward us. This is called the *crescent* moon.

(2) Next we see her a half-circle. The convex limb is still turned toward the west and the straight side faces east. This is called the *first quarter*.

(3) Then we find the moon somewhat like a foot-

ball, the western edge is still circular and the eastern edge is still elliptical, curved outward instead of inward, as in the crescent moon, thus forming more than half a circle. This is called the *gibbous* moon.

(4) Now, about fifteen days from new moon, our satellite has reached a point in the heavens directly opposite to that which the sun occupies. She is then in *opposition*, the whole illuminated side is turned towards us, and we see her full circle. The moon is now on the meridian at midnight, and rises in the east as the sun sets in the west. This is called *full moon.*

(5) The moon, passing on in her orbit from opposition, presents all the phases already described, but reversed. From full moon onward for a week she is gibbous again. But the elliptical side now faces the west and the circular side the east. She now rises an hour later each evening, and in the morning lingers high in the western sky after sunrise.

(6) She now comes back to a half-circle again, but we notice her position is reversed, the circular limb turned to the east and the straight side to the west. This is her *third or last quarter.*

(7) She now decreases again to the crescent form, but, as the bright hemisphere constantly faces the sun, the horns are now turned toward the west. She is now seen in the eastern sky just before sunrise.

(8) The moon now again reaches the point from which we started, the illuminated side is completely turned from us, and, coming into *conjunction* with the sun, is lost in his rays.

This journey from new moon to new moon occupies 29½ days—a *lunar month.*

4. **Earth Shine.**—Did you ever see "the old moon in the new moon's arms"? That is, the old moon as a dark globe, shedding a faint light, filling the slender crescent of the new moon.

This phenomenon is caused by the light which is reflected from the earth (earth shine) to the surface of the moon. The reflected light from the earth is equal to that of twelve full moons.

5. **Hunter's Moon and Harvest Moon.**—The moon rises on an average 50 minutes later every night, but the difference of rising (or of setting) from one day to another may sometimes be less than half an hour, and again, about a fortnight later, a full hour and a quarter. Near the time of the autumnal equinox, the moon, at her full, rises about sunset for a number of nights in succession. This produces a number of brilliant moonlit evenings. It is the time of harvest in England, and thus has been called the *Harvest moon.* A month later, the same occurrence takes place, and the October full moon is called the *Hunter's moon.*

6. **Wet Moon and Dry Moon.**—At new moon, when the crescent lies almost perpendicular to the horizon, the moon is commonly known as a *wet moon*, and when it is almost horizontal, the moon is called a *dry moon.* A moment's reflection will remind us that the horns of the moon must point *from the sun*, so that the position of the crescent must entirely depend on the relative position of the sun and moon, and, therefore, be purely astronomical, and not

meteorological. The form of the crescent has no connection whatever with the weather. Neither do the phases of the moon have any effect on the curing of pork, making of soap, etc., as common people seem to believe.

7. **Seasons.**—The axis of the moon is nearly perpendicular to the plane of her orbit, therefore there can be no change of seasons. During nearly fifteen of our days, the sun pours down his rays upon the moon. No atmosphere intercepts this scorching heat. No clouds lend their grateful shade. This day is succeeded by a night of equal length, and of arctic cold, for the moon is not enveloped during this long period by a cushion of warm air, as is our world, and there is no atmosphere around the moon to prevent the great heat of the long day from radiating into space.

8. **Telescopic Features.**—The great modern telescope brings the moon within 150 miles, and as a result much detail of her inexpressibly lovely scenery can be made out.

The surface of the moon is torn and shattered by fearful though now extinct volcanic action. The crust is pierced by craters, whose awful chasms and irregular edges testify to the great convulsions our satellite has undergone. One astronomer has counted 33,000 craters in the moon; and, as the part of the moon turned from us may be supposed to contain features similar in kind to those on the hemisphere so familiarly known, there are probably at least 60,000 craters on the entire surface. These lunar volcanoes are well shown in the accompanying photograph.

Lunar Volcanoes.

Nearly 40 lunar peaks are higher than Mount Blanc. The Leibintz Mountains, perhaps the highest on the moon, are from 30,000 to 36,000 feet high, much higher than the highest peaks on earth. The crater of Copernicus is 50 miles in diameter, and the walls are 13,000 feet in height.

9. **If one were to visit the Moon.**—Of course no human being could live on the moon. Absence of air and water means absence of life, at least in the forms such as are known to us. But, if we could visit her, "how strange the lunar appearance would be to us! The disc of the sun seems sharp and distinct. The sky is black and overspread with stars even at mid-day. There is no twilight, for the sun bursts instantly into day, and, after a fortnight's glare, as

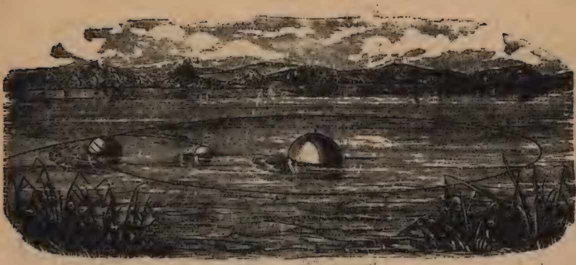
suddenly gives place to night; no air to conduct sound; no clouds; no winds; no rainbow; no blue sky; no gorgeous tinting of the heavens at sunrise and sunset; no delicate shading; no soft blending of colors, but only sharp outlines of sun and shade.

"The moon is a fossil world, an ancient cinder, a ruined habitation perpetuated only to admonish the earth of her own impending fate, and to teach her occupants that another home must be provided which frost and decay can never invade. The moon was once the seat of all the varied and intense activities that now characterize the surface of our earth. At one time its physical condition was like that of the parent earth, from which it had just separated; but, being smaller, it cooled faster, and its geologic periods were correspondingly shorter. Its life age was perhaps reached while the earth was yet glowing."—*Steele's Descriptive Astronomy.*

CHAPTER III.

ECLIPSES OF THE SUN AND MOON.

Solar Eclipses.—Lockyer beautifully says: "We may imagine the earth floating around the sun on a boundless ocean, both sun and earth half immersed in it. This level, this plane, the *plane of the ecliptic* (because all eclipses occur in it), is used by astronomers as we use the sea-level. We say a mountain is so far above the level of the sea. The astronomer says the star is so high above the level of the ecliptic."

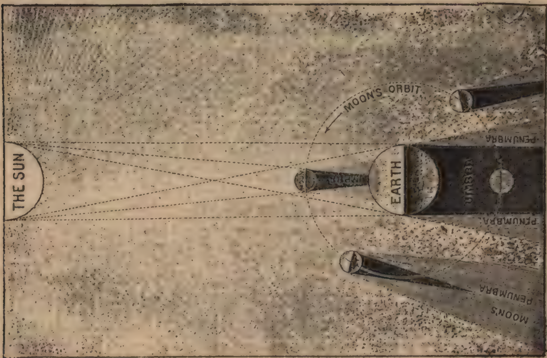


Illustrating the Plane of the Ecliptic (after Jackson).

In the above cut let the largest sphere represent the sun, the smallest one the moon and the third the earth. Then the level surface of the water will represent this *plane of the ecliptic.* To an observer standing upon the ball representing the earth the other ball would stand in the surface of the water; thus the plane of the earth's orbit is also the plane of the sun's apparent path, or ecliptic.

Now if the orbit of the moon, as shown in the picture, lay in the plane of the ecliptic, it is clear that once each month the moon must come directly between the earth and the sun and an eclipse of the sun occur. That is, there would be an eclipse of the sun every new moon. Also, it will be readily seen, that the earth must, once each month, come directly between the moon and sun and an eclipse of the moon take place. That is, there would be an eclipse of the moon every full moon. Instead, however, of the orbit of the moon lying in the plane of the ecliptic, it is inclined to that plane at an angle of about $\frac{5}{7}°$. The points where the orbit of the moon cut the ecliptic are called *nodes.* Then an eclipse of

the sun can occur only when the moon is between the earth and the sun (new moon), and at or near a node.



How Eclipses of the Sun and Moon take place (after Todd).

From the above figure it will be seen that the shadow of the moon cast upon the earth is in shape an inverted cone. This dark shadow is called the *umbra*. As the moon is smaller than the earth her cone of shadow is too small to cover the entire globe. The width of the space covered cannot exceed 180 miles, but, as the earth is constantly rotating on its axis during the duration of the eclipse, the shadow may travel over a large surface. People living in this region witness a *total eclipse*.

Completely surrounding the umbra is a less dense shadow, from which the sun's light is only partly excluded. Within this region there is a *partial eclipse*.

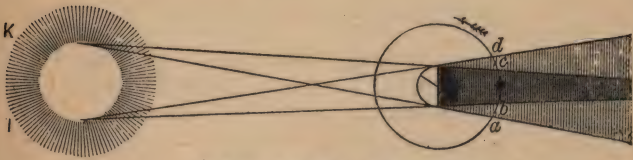
2. General facts regarding Solar Eclipses.—If we remember the following facts they may guide us in understanding the phenomenon of solar eclipses:

(1) An eclipse of the sun can occur only at new moon. That is, at *conjunction*.
(2) The moon must be at or near a node.
(3) An eclipse is not visible over the whole illuminated side of the earth.
(4) The longest duration of an eclipse is about 12 minutes.
(5) There cannot be more than five nor less than two solar eclipses each year, but very few of these are total eclipses.

3. **Phenomena of a Solar Eclipse.**—During a total eclipse the darkness is so intense that the brighter stars and planets are seen, birds cease singing and fly to their nests, flowers close, a sudden chill falls on the earth, men take on a cadaverous hue and look at each other and behold, as it were, corpses. When the moon reaches just the point where she first shuts off completely the light of the sun, the solar corona flashes out, and the total eclipse begins.

Corona of 1878 (Harkness).

4. Lunar Eclipses.—An eclipse of the moon is caused by the earth coming directly between the sun and the moon. This can occur only at full moon—*opposition*. The moon must also be at or near a node.



Eclipse of the Moon (after Steele).

This cut shows the position of the sun and moon during an eclipse of the moon. The space between the lines K*c* and I*b*, on the opposite side of the moon from the sun, represents the *umbra*. Outside of this, where the sun's light is only partially cut off by the earth, is the *penumbra*. From *a* to *b* the moon is only partially eclipsed. From *b* to *c* she is totally eclipsed. From *c* to *d* the sun's light is again only partially shut off from the moon.

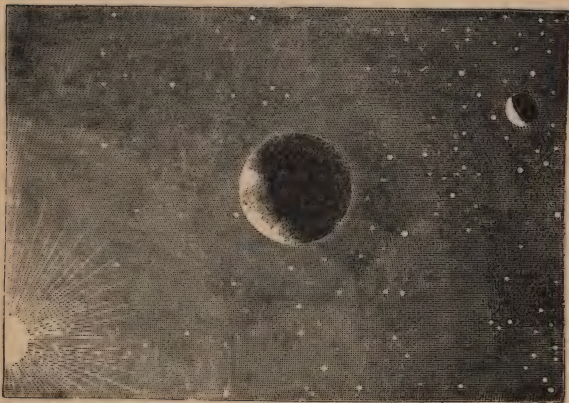
PART II.

THE EARTH

CHAPTER IV.

THE SHAPE OF THE EARTH.

1. **The Rotundity of the Earth.**—The earth is a great spherical ship, carrying you swiftly onward



Earth and Moon in Space.

in the ocean of space. We are to learn that the earth is a planet shining brightly in the heavens, and appearing to other worlds as a planet does to us. We

are to learn that it is flying along its orbit with a speed incomparably greater than the swiftest express train; that it is hanging in space held by the invisible power of gravitation.

2. What made the Earth Spherical?—The same force that draws the particles of a raindrop together and makes it spherical; the force that caused the molten metal dropped from a shot tower to form the tiny spheres of lead we call shot; this universal force—*the attraction of gravitation*—caused the earth to assume the form of a sphere.

When the matter which constitutes our earth separated from the sun (see Nebular Hypothesis in our Physical Geography), this attraction, acting on the particles of matter, first drew two or three together, forming a small body, which attracted the neighboring particles more powerfully, thus causing them to gather round this body as a centre, and from the continuation of this process the earth was formed. Each particle, acting under the force of gravity, would endeavor to approach as near as possible to the centre, and thus form a sphere, just as a number of men, crowding around an object, form a circle. In this way we *account for* the spherical shape of the earth.

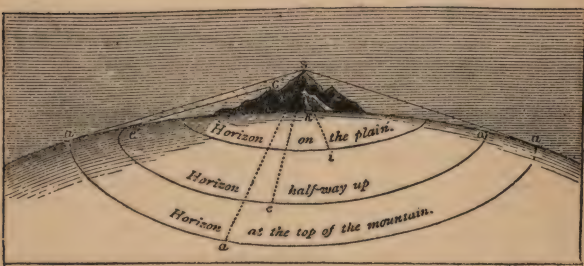
3. How we know the Earth is Spherical.—The original idea of the earth was that of an immense, flat, circular plane, around which Oceanus flowed like a vast river. The sky was a hollow hemisphere turned downward over it, through and across which the heavenly bodies coursed for human convenience and pleasure. We now know that the earth is round because:—

(*a*) The curvature of the earth may be actually seen. As you stand on the shore and watch a vessel sailing away to sea, the hull of the vessel will appear to sink below the water, and the last to disappear will be the masts and sails. This is caused by the fact of the intervening "hill" of water.

(*b*) Navigators have sailed around the earth. Final doubt of the shape of the earth was swept away when Magellan, in the 16th century, circumnavigated the globe.

(*c*) The shadow of the earth on the moon during an eclipse of the moon is always circular. (See Eclipses, Chapter III.)

(*d*) The horizon expands as we ascend an eminence. If we climb a hill we can see farther than we can from its foot. This is not because our eyesight is improved, but because the curvature of the earth shut off the view of distant objects when we stood at the foot of the hill, and when we reached the top we could see farther over the side of the earth.



The Horizon on a Round Earth.

A person standing on top of the mountain will have the largest horizon. The person at the foot of the mountain will see least.

(*e*) The pole star seems higher in the heavens as we pass north. This would not be so except the earth were spherical; if the earth were flat the pole star would be seen at the same height by all persons on the earth.

(*f*) We may prove that the earth is spherical by the aid of the electric telegraph. If the earth were flat then the sun would rise on all parts of the earth at the same time; if it is spherical the sun cannot rise at the same time on all parts of the earth, but must be rising at some place at all times. Now, if at 10 a.m. at Chicago the telegraph operator asks New York the time, he will receive for answer 11 a.m.; if he asks Denver he will receive for answer 9 a.m. This difference in local time can only be explained by concluding that the earth is spherical.

(*g*) All the other planets are spherical. Then, reasoning from analogy, our planet is spherical. This is the strongest of all the proofs.

4. The Earth is not a Perfect Sphere.

(1) First, the earth is not a *perfect sphere*, because its surface is uneven. Mountains, hills and valleys diversify the face of our earth. But, when we consider that the height of the loftiest mountain is no greater compared to the volume of the earth than is a grain of sand to the volume of a globe sixteen

inches in diameter, we at once see that they merely *roughen* its surface to a very slight degree.

(2) The earth is not a *perfect sphere*, because it is flattened at the poles. The true shape of the earth then is an *oblate spheroid*. The diameter of the earth from pole to pole is 7,900 miles; in the plane of the equator it is 7,927 miles. Each pole is then depressed about 13½ miles, a little more than twice the height of a very high mountain.

5. What made the Earth an Oblate Spheroid?—This flattening of the earth at the poles is caused by the earth's rotation. When the earth was in a molten condition (see Nebular Hypothesis) the particles at the equator would tend to fly off into space from the centrifugal force due to the rotation of the earth on its axis. This would cause the plastic earth to bulge out at the equator and sink in at the poles. In this way we *account for* the *real* shape of the earth.

6. How we know the Earth is not a Perfect Sphere.

(*a*) By analogy we conclude the earth is flattened at the poles. All rotating bodies are subject to the law which flattens their poles. We know from observation that the other planets are flattened at their poles. Hence we reason that the earth must also be flattened at its poles.

(*b*) A second proof is found in the difference in the weight of a body when weighed at the equator and again near the poles. The farther a body is carried above the surface of the earth the less it

weighs, and the nearer a body is carried to the centre (granted it is above the surface) the more it weighs. Now, it is found that a body weighs more near the poles than it does near the equator. Thus we conclude the poles are nearer the centre of the earth than is the equator. That is, the earth is flattened at the poles.

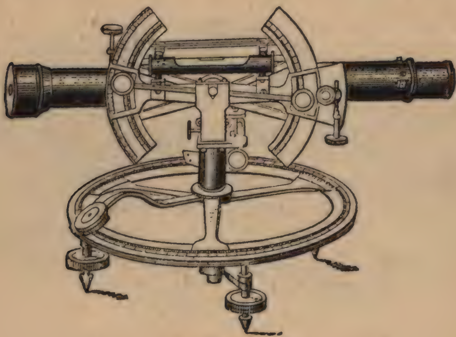
A similar proof is found in the pendulum of a clock. A clock marking seconds at the equator will, if carried to, say, Winnipeg, gain time. While, if one marking seconds at Winnipeg be carried to the equator, it will lose time. The reason for this is found in the following: The attraction of gravity causes the pendulum to swing, and the nearer the centre of the earth it is the faster it will swing. The pendulum, since it swings faster at Winnipeg than it does at the equator, must be nearer the centre of the earth at the former than at the latter place.

(*c*) The earth is known to be flattened at the poles by actual measurement. The north star remains apparently motionless in the sky, excepting when we move towards or from it. If we approach the pole star over one degree of latitude, the star appears to rise one degree towards the zenith. By means of this it is possible to measure with great accuracy the length of a degree on any part of the earth's surface. Now, if the earth were a perfect sphere, the length of a degree would be the same no matter where measured; but such is not the case. A degree of latitude is 365,744 feet long in Sweden and 362,956 feet in India. This shows that, since the degree at the poles is longer than a degree at the equator, it must be a degree of a larger circle. That is, the earth must be flattened at the poles.

CHAPTER V.

THE SIZE OF THE EARTH.

1. How to Measure the Earth.—We have already found out the shape of the earth; now we come to the discussion of its size. We are to find out how far it is round the earth at the equator, how far from pole to pole. It is very plain that we cannot set out and measure it with a tape line. That would take too long and be too inaccurate. But we may measure



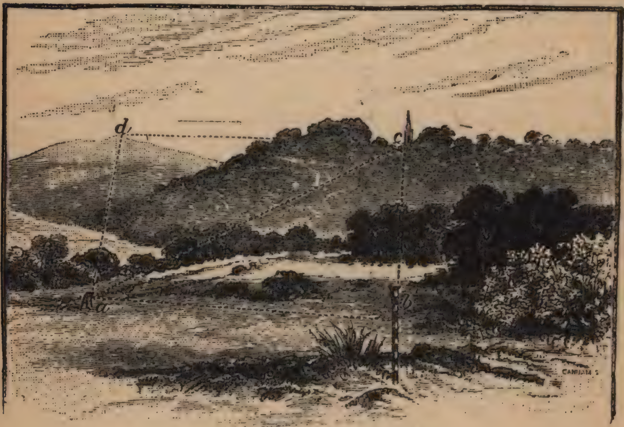
A Theodolite.

a small portion of the way round, say a mile, with great accuracy, and from this, as a first step, arrive at the whole distance round the globe.

In order that we may understand how this is done, it will be necessary to know something about the science of triangles. You know that, if the length of the base of a triangle, and also the angles at the base, are given, the length of the sides and the

remaining angle may be found. This is the fact on which all measurements that cannot be made by an actual tape are based.

Suppose we wish to find the distance from the man at *a* to the church spire, as shown in the picture. We would first measure with great care a base from *a* to *b*. Let this be 100 yards in length. Then *a b*



Measurement by Triangulation.

is the base of our triangle. We now go to the end *a*, and look at the church spire through an instrument called a *theodolite*, and we find that the line *a c* along which we look makes, with the line *a b*, an angle of 87° 8′.

Now going to *b*, and repeating the observation, we find that the line *b c* makes an angle of 87° 8′ with the line *a b*.

Now we have a triangle *a b c*, of which we know the length of the base *a b*, and the size of the two angles at the base *c a b* and *c b a*. Then from the science of geometry, we can readily find the length of *a c* and *b c*. For instance, we might cut a perfect model of the triangle *a b c* from a piece of cardboard, having the base one inch in length instead of 100 yards, and having the angles at the base exactly equal to the two angles we before measured, that is, 87° 8′. Then, carefully measuring the sides of our model, we would find them to be each 10 inches in length. Now, as the base of this model triangle is only $\frac{1}{3600}$ of the triangle *a b c*, the side of the model is only $\frac{1}{3600}$ of the side of the triangle *a b c*. That is, *a c* is 3600 x 10 inches, or 1,000 yards in length.

Now, from our short base line of 100 yards, which we could measure with great accuracy, we have found with absolute accuracy a line *a c*, 1,000 yards in length, and the line *a c* may be now used as a base line to measure the distance to some point still farther away than the church spire. For instance, if we wish to find how far it is to the top of the distant mountain top in the picture, we proceed as before, using *a c* as our base line. Then in the triangle *a c d*, we know the length of the base *a c*, the angles *c a d* and *a c d*. From this we find *a d* to be, let us say, 10 miles. Then we may use *a d* as a base to find the distance of still farther objects, and so on. And so it is possible to go on increasing the length of our measurements as long as we can see the object whose distance from us we want to measure. This is the way in which measurements of the earth's surface are taken. It is by this method of *triangulation* that the most accurate surveys of a country can be obtained.

2. To find the Length of a Degree.

Let us now see how what we have just learned of measuring long distances can help us in our problem of finding the circumference of the earth.

Degrees in a Circle.

Let the circle O O represent the circumference of the earth. Of course you will remember we have learned in Chapter IV. that the earth is not a perfect sphere, and therefore that its circumference cannot be a perfect circle. But for our present purpose we will let this circle represent the outline of the earth.

For convenience the circumference of every circle is divided into 360 equal parts called degrees. There is no reason, other than convenience, why this number of divisions should be taken; but you will notice that 360 has more factors than any other number you could choose, and it has been fixed on for that reason alone. Each degree is again divided into 60 minutes and each minute into 60 seconds. If in our figure N P is the north pole, S P the south

pole and E E the equator, we shall readily see that from the equator to the north pole will be 90 degrees.

Now if we knew the length of one degree we could readily find the whole circumference of the earth by multiplying the length of one degree by 360. The question then is, *Can we measure the length of a degree?* and, if so, how? Unfortunately for us there are no marks on the earth's surface to show us where one degree starts and another ends. But we have in the sky an object, the north star, from which we can always find how many degrees north of the equator we may be. The north or pole star may be easily found on any clear night from the following diagram.

The Great Bear and the Pole Star.

The Dipper or Great Bear is known to everyone, and is seen shining in the northern sky every night. The two outer stars of the Dipper point almost directly to the north polar star, as the above cut shows.

If we were at the equator, this pole star would rest on the northern horizon; if we were at the north pole, it would be directly overhead. Thus it will be seen that, for every degree north we should travel, this star would rise one degree higher in the sky. Then, to find two places which are one degree apart, we would have to take, with a sextant, the altitude of

An Observation from a Lighthouse.

the north star. Let it be, say, 45°. That is, the place is 45° north of the equator. Then moving north, find a place on the same meridian where the north star is 46° above the horizon or 46° north of the equator. These two places must be one degree apart. Then, by triangulation, find the exact distance between these places.

This problem is usually solved by observing the sun. At the vernal equinox, the 20th of March, the sun is standing exactly over the equator. Then, if on the 20th of March we find, as in the cut given, the altitude of the sun from the horizon, and subtract this from 90°, we must get the distance of the sun from the zenith, that is, the distance from the equator (the place of the sun) to the lighthouse (the place where the observation was taken).

Let the angle between the line *A H* and *A S* be 38° 51′. Then the angle between *A S* and *A Z* must be $90° - 38° 51' = 51° 9'$, That is, the distance from the equator to the lighthouse is 51° 9′. Now, all that is to be done is to find, directly north of this lighthouse, a place such that its distance from the equator would be 52° 9′, and then, as before explained, find the exact distance in miles between those places. If the observation should be taken at any time other than the equinoxes, we would have to add or subtract the declination of the sun (the sun's distance north or south of the equator) to or from the above result. The declination of the sun for every day in the year is given in every nautical almanac.

These measurements have been carefully and accurately made in many countries, and it has been found (as explained in Chapter IV.) that degrees in northern regions, measured from north to south, are longer than degrees near the equator, but that degrees on the equator, measured from east to west, are uniform in length. A degree on the equator is $69\frac{1}{6}$ statute miles, while a degree from the equator north is $68\frac{3}{4}$ miles, a degree half way to the pole is 69 miles, and a degree at the pole $69\frac{3}{8}$ miles. This gives the polar diameter

as 7,900 miles, and equatorial as 7,927 miles, or a flattening of the poles of about 13½ miles, as before explained. This will give the polar circumference as about 24,819 miles, and the equatorial as about 24,903 miles.

Weighing the Earth (after Todd).

1. How the Earth is Weighed.

The mass of the earth is 6,000,000,000,000,000,000,000, six thousand millions of millions of millions of tons. The reader will at once admit that this does

not, in the least, aid in realizing the earth's weight. But it may arouse curiosity in regard to the manner in which the earth has been weighed.

Several methods have been employed; the outline of the first one ever tried is given on preceding page. The figure represents a section of the earth surmounted by a rather abrupt mountain. From *a* and *b* straight lines are drawn from the centre of the earth. These lines, if produced backwards, would point to the zenith of the stations *a* and *b*. A plumb line is now suspended at *a*, and another at *b*. The attraction of the mountain mass draws the plumb lines towards itself. The result is that the difference of latitude of *a* and *b* is made to appear greater than it really is. The true latitude of *a* and of *b* is found by surveying around the mountain. This survey must also be of such a character as to give the weight of the mountain in tons. Then by a mathematical calculation the earth is weighed against the mountain. the earth's mean density has been found to be 5.6; that is, the earth is 5.6 times heavier than a globe of water the same size.

CHAPTER VI.

THE MOTIONS OF THE EARTH.

The earth performs three motions.

(*a*) It rotates upon its axis once in twenty-four hours.

(*b*) It revolves around the sun once a year.

(*c*) It moves onward through space with the rest of the solar system.

1. ROTATION.

1. What keeps the Earth Moving?

If we set a top in motion, it soon stops. We know that friction between the top and the surface upon which it spins, and the medium in which it spins, overcomes its motion.

Now, the earth is an immense top, but since it spins in empty space, there is no friction to overcome its motion. It must be remembered that the atmosphere rotates with the earth.

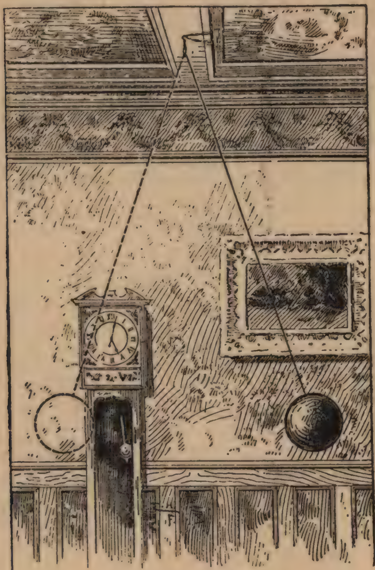
2. Proofs of the Earth's Diurnal Motion.

(1) Since the sun and stars are at such great distances from us, it is more simple to believe that the earth turns on its axis, thus making them appear to move around the earth, than to believe that they really do perform such motions.

(2) If the earth rotates on its axis from west to east, then it must tend to throw bodies from its surface in the direction in which it is rotating, just as a grindstone throws drops of water from its surface.

Proof of Earth's Rotation (after Jackson).

A stone dropped from a cliff always falls a little *east* of a vertical line. That is, it is ***thrown a little eastward*** by the earth's rotation. If the earth's rotation were rapid enough, the stone would fly off along



A Pendulum.

the line A E. This would be so if the rotary motions should become swift enough to reduce the day to eighty-four minutes. But, as the rotation is not nearly so rapid, the stone's departure from the vertical line A C is comparatively slight. This distance C D

furnishes mathematicians with a means of determining the rate at which the earth rotates.

(3) Suspend a ball of lead by a fine thread attached to the centre of a ruler. Hold the ruler in both hands, and set the ball swinging in the plane of the stick. Then, without raising or lowering it, quickly swing the ruler quarter way round its centre in a horizontal plane. The ball keeps swinging in the same plane as before, although it is now swinging at right angles to the ruler.

Now take a heavy leaden ball, fasten it to the roof, as in the picture, by a fine steel wire, and set it swinging, so that the fine point in the pendulum end will make a slight scratch on the smooth floor. The south end of the floor, being nearer the equator than the north end, will travel eastward a little faster than the north end will; and as the plane of oscillation of the pendulum does not change, the marks caused by the sharp point will not all lie in the same place, but a more or less star-shaped figure will result. At the equator the pendulum marks only one line, but the nearer the pole the nearer the figure approaches the form of a star.

3. Solar and Sidereal Days.

(1) *A Sidereal day* is the exact interval of time in which the earth rotates on its axis. It is found by marking two successive passages of a star across the meridian of any place. This is absolutely uniform, and occurs every 23 hours, 56 minutes and 4 seconds of mean solar time.

(2) *A Solar day* is the interval between two successive passages of the sun across the meridian of any place. If the earth were stationary, the solar

day would be of the same length as the sidereal day; but, while the earth is turning on its axis, it is also going forward in its orbit. Thus, when the earth has made a complete rotation, it must perform a part of another rotation, in order to bring the same meridian vertically under the sun.

These solar days are of unequal length. To obviate this difficulty astronomers have adopted a *mean day*, which is the average length of the solar days in the year. The clocks in common use are regulated to keep mean time. Thus the sun and our clocks do not always mark the same time. On the first of November the sun is sixteen and a quarter minutes too fast; and on the tenth of February it is fourteen and a half minutes too slow.

This *mean solar* day is divided into 24 parts called hours. Thus 24 hours of mean solar time are equal to 23 hours, 3 minutes, 56 seconds of sidereal time. From what has been said, it follows that the earth makes 366 rotations in 365 solar days.

4. The Effects of the Earth's Rotation.

(*a*) *The determination of an axis, poles and equator.*

The earth rotates upon its shortest diameter, called its axis.

The ends of the axis are called *poles*. A line drawn around the earth, mid-way between the poles, is called the equator.

(*b*) *The flattening of the poles.*

See Chapter IV., Section 5.

(*c*) *The apparent rotation of the heavens in the opposite direction.*

By observing the heavens it will be seen that the north star remains stationary, while the stars near the pole star seem to move in small circles around it every twenty-four hours. Stars farther off describe larger circles, while those over the equator describe the largest of all.

(*d*) *Alternation of day and night.*

The sun shines upon one-half of the earth at a time. The other half being turned away from the sun is in darkness. As the earth rotates, each point on its surface is carried necessarily into the light and into the darkness, one day and one night marking a complete revolution.

2. REVOLUTION.

1. How we Know the Earth Revolves Around the Sun.

This is apparent from the change in the appearance of the heavens in different months.

Let *a b c d* be the orbit of the earth, and C D A B the sphere of the fixed stars, surrounding the sun in every direction. When the earth is at *a*, the stars about C (Capricornus) are on the meridian at midnight. The stars at A (Cancer), on the contrary, will be invisible.

In three months, the earth has passed over one-fourth of its orbit, and has arrived at *b*. Stars at D (Aries) now appear on the meridian at midnight, while those at C (Capricornus), which previously occupied their places, have descended toward the west; and those at A (Cancer) are just coming into sight in the east.

In three months more the earth is at *c*. Stars

The Earth's Real and the *Sun's* Apparent Yearly Revolution (after Jackson).

about A (Cancer) shine in the midnight sky, those at D (Aries) have in their turn sunk in the west; while stars at C (Capricornus) are hidden in the daylight.

One revolution of the earth will bring the same stars again on the meridian at midnight. Thus, the varied aspect of the heavens in the summer and the winter skies is a proof of the earth's motion around the sun.

2. What makes the Earth move round the Sun?

Take a stone tied to an elastic cord and swing it

around your hand. This will illustrate the earth's revolution around the sun, and also the two forces which produce the revolution. There is the force tending to throw the stone *from* the hand, and the force in the elastic cord tending to pull the stone *towards* the hand.

So long as these forces remain equal the stone

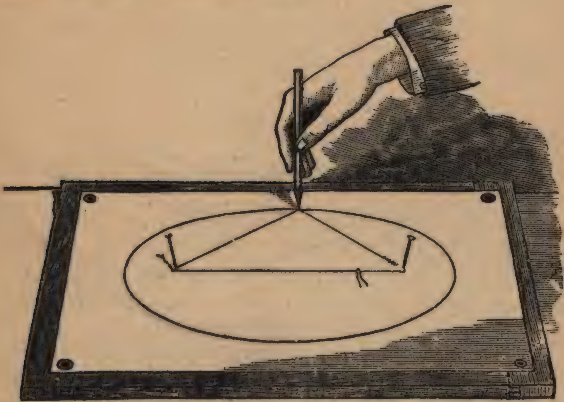
Centripetal and Centrifugal Forces.

must move in a curve around the hand. But, if the cord should break at A, the stone would fly off in the line A B, or, if at C, it would take the direction C D.

The force which tends to throw the earth from the sun is called a *centrifugal* (sen-trif′-yu-gal) force, and that which tends to draw it to the sun is called a *centripetal* (sen-trip′-e-tal) force. These two forces cause the earth to move around the sun.

3. Form of the Earth's Orbit.

If we take a sheet of paper and put two tacks through it, as in the picture, then take a piece of twine and tie the two ends together so as to form a loop, which we pass around the two tacks; next, place a pencil in the loop and, keeping the twine stretched, move the pencil around once, we will produce a pretty curve, called an *ellipse.*



How to Draw an Ellipse.

The orbit of the earth is an ellipse. To the astronomer, the ellipse is the most important geometrical figure. All the planets move in elliptical paths. The two pins are called the *foci* of the ellipse. The long diameter passing through the foci is called the *major axis*. The short diameter is called the *minor axis*.

4. Why the Earth's Orbit is an Ellipse.

In order to complete a revolution around the sun in 365¼ days, the earth moves at the enormous velocity of about 1,100 miles per minute; but, as already stated, this motion is not uniform. It moves faster when near the sun (perihelion), and more slowly when distant (aphelion).

The Earth's Orbital Motion.

This will be plain from the above cut. Let A B C D be the orbit of the earth. The centrifugal force (earth's inertia) urges it in the direction of the tangents *t*. The centripetal force (sun's attraction) draws it in the direction *s*. At B and D this attractive force neither increases nor diminishes the earth's speed, but only bends the line of motion into a curve. At A, however, this force of attraction adds to the speed of the earth, and from A to B the earth travels with an ever-increasing velocity. This increased speed enables the earth to pass B, and afterwards increase its distance from the sun. At C, however, gravity retards the earth's velocity, and so the earth is retained in its orbit, and is drawn around the point D.

Thus the earth's velocity is greater while passing through the arc xBy, and less while passing through yDx.

5. Proof that the Earth's Orbit is an Ellipse.

(*a*) The angle which the sun seems to fill, as seen from the earth, is called the sun's apparent diameter. If we measure the sun's diameter to-day and again to-morrow, and so on throughout the year, the measures will be found to differ very materially.

It is not reasonable to suppose that the size of the sun itself varies in this manner. Therefore, we can only conclude that our distance from the sun is a variable quantity. Then the earth's orbit cannot be a circle, unless the sun is not at the centre of this circle.

To find the exact form of the orbit, all we have to do is to take a point to represent the sun, draw from this point 365 lines to represent the different positions of the earth when the observations of the sun's diameter were made. Cut off from these radial lines lengths proportional to the observed diameters, and then draw a regular curve through the ends of the radial lines. This curve will be found to be an ellipse differing but slightly from a circle. The radial point will be found to be one of the foci. The earth's orbit round the sun, then, is an *ellipse*, with the sun in one focus.

(*b*) Tycho Brahe, the great Danish astronomer, after years of patient toil and observation determined, about the year 1587, that the planet Mars was irregular in its motion. The patient old astronomer tracked Mars through all his capricious wanderings. The great Kepler, availing himself of Tycho's labor, commenced to search out the kind of figure in which Mars was moving. He tried various circles with the centers in different positions, but none would account for

the irregularities of the troublesome planet. It would not do, the movement was not circular. He then tried the ellipse, and after long calculations he succeeded in finding one particular ellipse, placed in one particular position, which would just explain the strange wanderings of our erratic neighbor. He found also that the sun was placed in one focus of this ellipse, else the motion of the planet would be different from that which Tycho had found it to be. From the elliptical orbit of Mars it was only a step to the elliptical orbit of our earth.

6. Effect of the Earth's Revolution.

(*a*) The *apparent* yearly revolution of the sun and stars around the earth through the twelve signs of the Zodiac.

(*b*) The succession of the seasons. This will be fully discussed in a succeeding chapter.

7. Solar and Sidereal Year.

(*a*) The *sidereal year* is the interval of a complete revolution of the earth about the sun, measured by a fixed star. See Sidereal day. There are 365 days, 6 hours, 9 minutes, and 9.6 seconds of mean solar time in a sidereal year.

(*b*) The *mean solar year* (tropical year) is the interval between two successive passages of the sun through the vernal equinox. It comprises 365 days, 5 hours, 48 minutes, 46.7 seconds. The sidereal and solar year are not of the same length, because the equinoxes are not stationary.

3. ONWARD THROUGH SPACE.

The discussion of the motion of the earth with the

rest of the solar system in space is one which is too full of difficulties for these pages. The velocity and direction of this motion are largely questions of speculation. Recent discoveries have shown that the stars in the constellation of Hercules are apparently spreading apart, and it is therefore thought that the solar system is moving in that direction.

CHAPTER VII.

THE SUCCESSION OF THE SEASONS.

1. Causes of the Succession of the Seasons.

(1) The earth's revolution round the sun.
(2) The inclination of the earth's axis.
(3) The unchanging position of the axis.

2 The Inclination of the Earth's Axis.

The axis of the earth makes an angle of about $66\frac{1}{2}°$ with the plane of the ecliptic—a plane passing through the earth's orbit and the sun's centre. The axis, therefore, leans about $23\frac{1}{2}°$ ($90° - 66\frac{1}{2}°$) out of a perpendicular to the plane of the ecliptic. This angle constitutes the *inclination of the axis.*

This inclination is shown in the cut on page 70. The broad line E, which passes around the globe at an equal distance from the top and the bottom of the axis, is called the *equator*. The two points A and B are the poles of the earth, and the imaginary line passing through them is the *axis* upon which the earth rotates. The line A B cuts the *orbit* or path of the earth round the sun at an angle of $66\frac{1}{2}°$.

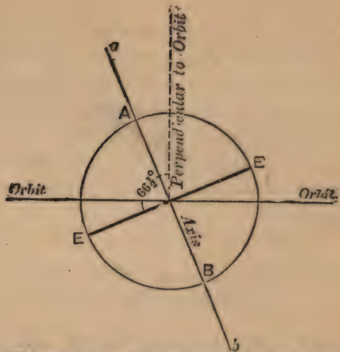


Diagram Showing the Inclination of the Earth's Axis.

It is a difficult matter to explain just what is meant by the plane of the ecliptic. A good way to illustrate it is to suspend a large sphere in water. Then take a ball, through which a knitting-needle has been thrust, to represent the axis, and on which the equator, tropics and polar circles have been carefully drawn, and suspend it also in the water, so that the equator rests on the surface. The surface of the water represents the plane of the ecliptic, and in this position the latter corresponds exactly with the plane of the equator. Now incline the axis until the surface of the water just touches the tropics. It will be found that the inclination of the axis is 23½°. This shows the true relative position of the earth and the plane of the ecliptic. See the cut on page 39.

3. Proof of the Inclination of the Axis.

We know that on the 21st of June the sun shines vertically on the Tropic of Cancer, while on the 21st

of December it shines vertically on the Tropic of Capricorn. This apparent movement of the sun from north to south is proof of the inclination of the axis, and, since these tropics are $23\frac{1}{2}^\circ$ north and south of the equator respectively, we at once see that the inclination must be $23\frac{1}{2}^\circ$ from the perpendicular to the plane of the earth's orbit—the *plane of the ecliptic.*

4. The Unchanging Position of the Axis.

Nature reveals nothing more permanent than *the parallelism of the axis of rotation* of any rapidly turning body. A top never falls so long as it spins, since its tendency to keep the different positions of its axis of rotation parallel is greater than the attraction of the earth. A slater, wishing to throw a slate from the roof to the ground, whirls it perpendicularly, and it strikes on its edge without breaking. Even a boy knows that his hoop will not fall so long as he keeps it rotating rapidly.

This wonderful law would lead us to suppose that the axis of the earth must always point in the same direction, even if we did not know it from direct observation. But since we always see the north star, summer and winter, at the same distance above the northern horizon, while all other stars seem to move from east to west, we at once conclude that the axis of the earth must point constantly to the north star. The north star must be imagined at an immense distance from the earth, so that the different positions of the axis of the earth, although parallel, will, like the parallel lines of a railway track, appear to meet in a single point in the distance.

5. The True North.

The axis of the earth does not point exactly to the north star, but to the *pole of the heavens*, which is one and a third degrees, or two and a half times the diameter of the moon, from it. The result is that the pole star appears to move in a small circle, five times the width of the moon in diameter, with the pole of the heavens as a centre. Therefore twice each day Polaris marks the true north.

The True Pole.

In the year 2100, A.D., Polaris will be only half a degree, or about the apparent diameter of the moon, from the pole, and will then slowly pass away from it, until, 12,000 years hence, the brilliant star Vega will fulfil the office of pole star for those who shall then live on the earth.


SUN
Ecliptic
Cancer
Equator
Capricorn
N
S

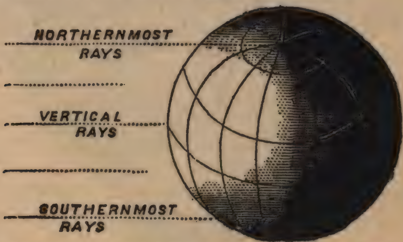
6. Diagram Showing the Change of Seasons. (See cut on preceding page.)

The average distance of the sun from the earth is 93,000,000 of miles. But, as the orbit of the earth is an ellipse with the sun placed in one focus, the earth approaches the sun at certain seasons and draws away from it at others.

The earth is the nearest the sun about the 31st of December. This point in the earth's orbit is called *perihelion* (*peri*, near; and *helios*, the sun). The earth is farthest from the sun about the 8th of July. This point in the earth's orbit is called *aphelion* (*ap*, from; *helios*, the sun). At perihelion the earth is 3,000,000 of miles nearer the sun than it is at aphelion.

7. Vernal Equinox, 22nd March, sun enters Aries.

If on the 22nd of March the vertical rays of the sun could leave a golden line on the earth as it rotates, they would mark the *equator*. Neither pole of the earth inclines towards or from the sun, but *sidewise*. The sun's light reaches to the north and to the south pole. Each hemisphere receives an equal portion of the sun's light and heat.



Earth at Vernal Equinox (after Jackson).

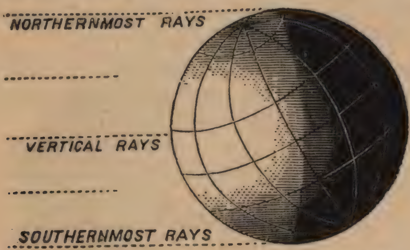
The Circle of Illumination—the line dividing light from darkness—passes through the north and south poles, cutting the equator at right angles, and, therefore, bisecting it and all the parallels of latitude, thus giving equal day and night all over the world. It is spring in the northern and autumn in the southern hemisphere.

As the earth moves on, the north pole begins to lean towards the sun and the south pole from it; the sun, therefore, shines vertically farther and farther north each day.

8. **Summer Solstice,** 21st of June, sun enters Cancer.

The vertical rays of the sun would now mark the Tropic of Cancer.

The north pole leans directly towards the sun, and the south pole directly from it. The sun is at his greatest northern *declination;* that is, he ascends the highest he is ever seen above our horizon, and apparently rises north of east and sets north of west.



Earth at Summer Solstice (after Jackson).

The sun now seems to stand still in his northern and his southern course; hence the name *Solstice*

(*Sol*, the sun ; *sto*, I stand). The northernmost ray of the sun reaches 23½° beyond the north pole, and would, if it left a golden track, mark the Arctic Circle as the earth rotates. The southernmost ray falls 23½° short of the south pole, and would mark the Antarctic Circle.

The Circle of Illumination passes from the Arctic Circle to the Antarctic Circle, cutting the equator at an acute angle, thus bisecting it, but cutting every parallel of latitude into two unequal parts. This gives unequal day and night all over the earth except at the equator. The northern hemisphere receives more than half the sun's light ; hence the days are long in the northern and short in the southern. It is summer in the northern and winter in the southern hemisphere.

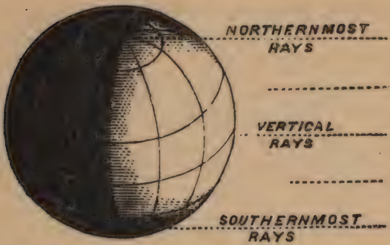
No point on the Arctic Circle passes out of the sunlight, and no point on the Antarctic Circle passes into the sunlight, during the earth's rotation; hence there is a 24-hour day on the Arctic Circle and a 24-hour night on the Antarctic Circle. It is the noon of the 6-month day at the north pole and the midnight of the 6-month night at the south pole.

As the earth moves on in its orbit, the poles incline less and less towards and from the sun, and the sun's vertical rays fall farther and farther south.

9. **Autumnal Equinox,** 22nd of September, sun enters Libra.

The vertical rays of the sun would again mark out the Equator.

All the phenomena of the Vernal Equinox are repeated, except that it is autumn in the northern and spring in the southern hemisphere.



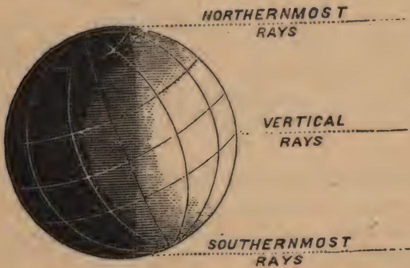
Earth at Autumnal Equinox (after Jackson).

As the earth passes on in its orbit, the north pole begins to incline from the sun and the south pole towards it; the sun, therefore, shines vertically farther and farther south each day.

10. Winter Solstice, 21st of December, sun enters Capricornus.

The vertical rays of the sun would now mark the Tropic of Capricorn.

The north pole leans directly from the sun, and the south pole directly towards the sun. The sun is



Earth at Winter Solstice (after Jackson).

at his greatest southern *declination;* that is, he descends the lowest he is ever seen, and rises south of east and sets south of west.

The sun again seems to stand still. The southernmost ray of the sun reaches 23½° beyond the south pole, and marks the Antarctic Circle. The northernmost ray falls 23½° short of the north pole and marks the Arctic Circle.

The Circle of Illumination occupies a similar position to that at the Summer Solstice, only the conditions are reversed. The southern hemisphere receives more than half the sun's light; hence the days are long in the southern and short in the northern hemispheres. It is summer in the southern and winter in the northern hemisphere.

No point on the Antarctic Circle passes out of the sunlight, and no point on the Arctic Circle passes into the sunlight; hence there is a 24-hour day on the Antarctic Circle and a 24-hour night on the Arctic Circle. It is the noon of the 6-month day at the south pole and the midnight of the 6-month night at the north pole.

We have now traced the yearly path of the earth, and noticed the course of the succeeding seasons and the varying lengths of day and night. The same series have been repeated through the ages of the past, and will be repeated in the time to come.

11. Seasons at the Equator.

Since the sun crosses the equinoctial twice during each year, there are two summers and two winters at the equator annually. Winter at the equator, of course, is much warmer than our warmest summer.

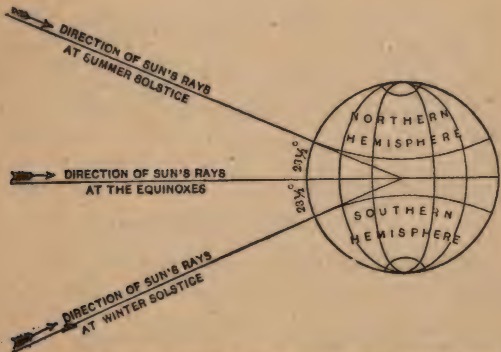
Practically the only seasons known in tropical climates are the "wet" and the "dry."

12. Summer Longer Than Winter.

As the sun is not in the centre of the earth's orbit, but at one of its foci, the earth from the time of the Vernal Equinox to the time of the Autumnal Equinox passes through more than one-half of its orbit. Also, as was shown in Section 5, Chapter 6, the velocity of the earth as it passes over this portion of its orbit is less than its velocity while passing over the shorter portion. The result is that the time from Spring to Autumn is shorter by eight days than the time from Autumn to Spring.

13. Vertical and Oblique Sun.

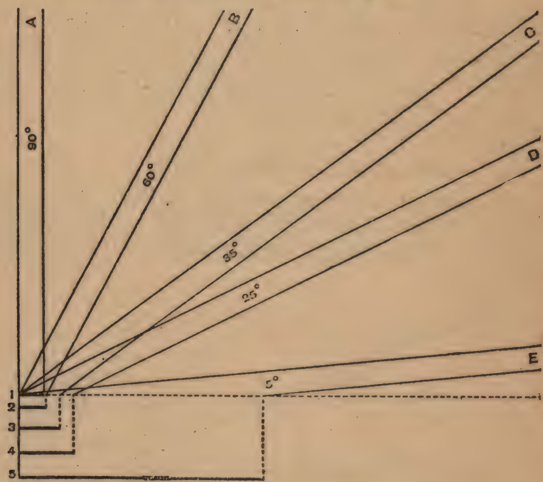
We have already seen that the vertical rays of the sun move from the Tropic of Cancer at the Summer Solstice to the Tropic of Capricorn at the Winter Solstice.



Direction of the Sun's Rays at Equinoxes and Solstices.

The result of this will be clearly seen. At the Summer Solstice the northern hemisphere will receive the *vertical rays* of the sun, and at the Winter Solstice the southern hemisphere will receive these vertical rays.

How great is the difference between the heat from vertical rays and that from oblique rays may be readily seen from the following diagram.



Vertical and Oblique Rays.

Let A represent a beam from the sun as it strikes the equator at the Vernal Equinox; that is, vertically.

Then B will represent a beam from the sun striking the earth at 30° north latitude at the same time,

C at 55° north latitude, D at 65° north latitude, E at 85° north latitude.

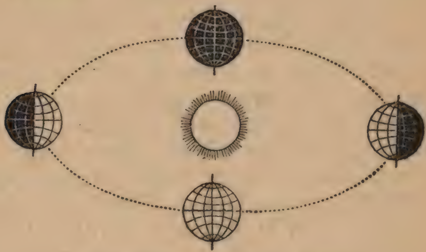
We at once see that the vertical beam A must bring more heat to the portion of the earth on which it falls than the oblique beams B, C, D, E. For, while all the beams, as represented in the drawing, are the same breadth, the whole of the beam A will be concentrated on the small space of ground numbered 1; the beam B, however, will be spread out over a much greater space marked 2; while C, D, E fall upon the still wider spaces marked 3, 4 and 5 – that is to say, the heat of an *oblique* beam will be spread out over a much larger surface than that affected by the *vertical* beam. The heat of the beam B is ¾, of C ½, of D ¼, and of E $\frac{1}{120}$ of the heat which the beam A brings to any one point. Thus we see that the heat of any part of the earth's surface will depend upon the angle at which the sun's rays strike it.

14. The Hottest and the Coldest Day.

Although the most direct rays fall at noon, the warmest part of the day is usually about 2 P.M. So we do not have our greatest heat at the time of the Summer Solstice, nor our greatest cold at the Winter Solstice. After the 21st of June the earth continues to receive more heat during the day than it loses during the night. Thus the great heat of an August day is not the result of the sun's heat for that day, but is the result of the accumulation of the heat of the preceding weeks. Thus, also, after the 21st of December the earth continues to lose more heat during the night than it receives during the day, and the greatest cold does not arrive until some time in January.

15. Earth's Axis Perpendicular to the Plane of the Ecliptic.

Then the plane of the ecliptic would coincide with the equator. The sun would always shine vertically on the equator.



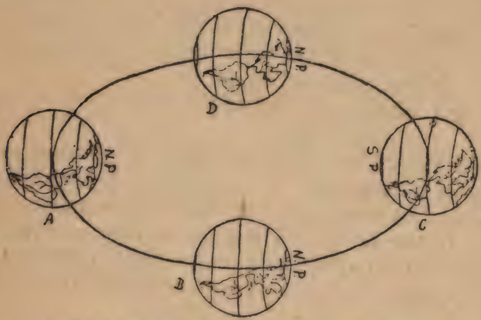
Axis Perpendicular to Ecliptic.

He would rise and set every day at the same points on the horizon. His northernmost ray would just reach the north pole; his southernmost ray, the south pole. There would be equal day and night all over the world. Near the equator there would be a fierce torrid heat, while north and south the climate would change into temperate spring, and, lastly, into the rigors of a perpetual winter. There could be no succession of seasons.

16. Earth's Axis Parallel to the Plane of the Ecliptic.

To a person standing on the equator, the sun would, after passing the Vernal Equinox, each day perform a smaller circle, and, rising like the threads of a screw, reach the north pole at the time of the

Summer Solstice. Here he would halt, and then day by day descend the same curve in an inverse manner.



Axis Parallel to the Plane of the Ecliptic.

In our own latitude the sun would make his diurnal rotations as described above. His rays would pass farther and farther beyond the north pole, until we would be in the region of perpetual day. The sun would then ascend in a spiral course to the north pole, and halting would commence to descend by travelling down the same spiral in an inverse manner.

As a result every part of the earth would be exposed part of the year to torrid heat and six months afterwards to frigid cold.

17. Conclusion.

We have now seen that the succession of seasons is due to the different angles at which the sun's rays strike the earth. They beat on us almost directly at midsummer, and fall very obliquely at midwinter.

We have also learned that these differences in direction are caused by the three things mentioned at the beginning of this chapter, viz:—

(1) The revolution of the earth around the sun.

(2) The inclination of the earth's axis, at an angle of 23½° from the perpendicular to the plane of its orbit.

(3) The parallelism of the axis at every part of the earth's path.

All these three are necessary to produce a succession of seasons. For example, (1) and (3) are assumed in paragraph 15; still no succession of seasons is the result. Then, by a simple experiment with a ball or apple, you may easily prove that (1) and (2) may be assumed with a similar result.

CHAPTER VIII.

THE VARIATION IN THE LENGTH OF DAY AND NIGHT.

The variation in the length of day and night has been very fully explained in Chapter VII. Here it would be well to summarize the facts.

1. Causes.

The causes of the variation in the length of day and night are the same as the causes of the succession of seasons. All three must be given.

2. Maximum Length of Day and Night.

Since, as has been stated in Chapter VII., the

Circle of Illumination always bisects the equator, giving half of it light and half of it darkness, there must be equal day and night at the equator during the entire year.

The longest day at the Tropics is 13½ hours, at the Polar Circles 24 hours and at the Poles 6 months.

The following table gives a detailed view of the length of the longest day over the whole world :

At degree of latitude	*Greatest length of day is*	*At degree of latitude*	*Greatest length of day is*
0.0	12.0 hours	65.8	22.0 hours
23.5	13.5 "	66.5	24.0 "
30.8	14.0 "	67.4	1 month
49.0	16.0 "	73.7	3 months
58.5	18.0 "	84.1	5 "
63.4	20.0 "	90.0	6 "

3. Curious Appearances of the Sun.

We know that the longer the day the farther north the sun appears to rise and set, and the longer the arch he describes in the sky. Continuing this, the sun would finally rise in the north and set in the north, describing a circle set obliquely in the sky, its northern edge resting on, and its southern edge rising 47° above, the horizon. This is the appearance of the sun to a man standing on the Arctic Circle at the Summer Solstice. His day is 24 hours in length. At midnight on the 20th of June the sun is seen to rise due north, and at midnight of the 21st he sinks from sight in the same place.

To a person standing near the north pole on the 22nd of March the sun appears to sweep horizontally around the sky in 24 hours. During the following

days this journey is repeated without any perceptible variation in the sun's distance from the horizon. It is, however, slowly rising until, on the 21st of June, it has reached an altitude of 23½°. Here it begins to slowly descend, its track being represented by a screw with a very fine thread. On the 22nd of September it again slowly sweeps around the sky, with its face half hidden below the icy sea.

The ordinary notion of the polar night needs some correction. It is true that the sun is below the horizon for nearly six months. But the duration of twilight is a matter not to be forgotten. In fact, the autumn and the spring twilights are protracted over 2½ months each, leaving only 6 or 7 weeks of absolute darkness. Also, since in high latitudes the moon, during its full phase, shines continually above the horizon, and, since the moon must "full" at least twice during the six weeks of darkness, the period of absolute night is reduced to about three weeks at the most.

CHAPTER IX.

THE ZONES.

The division of the surface of the earth in *astronomical* zones is a matter of very little importance. The discussion of *climatic* zones falls under the province of physical geography.

I. The Zones.

The astronomical zones are five belts into which the surface of the earth is divided by the Tropics and the Polar Circles.

2. Names and Boundaries.

(*a*) *Torrid Zone* (Lat., *torridus*, hot) is the belt between the Tropics of Cancer and Capricorn, and is, therefore, 47° wide.

(*b*) *Two Temperate Zones* lie between the Tropics and the Polar Circles, and are each 43° wide.

(*c*) *Two Frigid Zones* (Lat., *frigidus*, cold) lie within the Polar Circles, and have a radius of 23½°.

3. Characteristics of the Zones.

(*a*) *Torrid Zone*—(1) *scorching* heat; (2) *sun vertical* over every place twice a year; (3) days and nights differ in length very little during the year; (4) *vegetation* is luxuriant; (5) *animal life*—great variety—many of the largest animals in the world; (6) *inhabitants*—dark skinned, backward in civilization.

(*b*) *Temperate Zones*—(1) a milder or *temperate* climate; (2) the *sun* is *never vertical* over any place; (3) days and nights more unequal; (4) the *four seasons* are more definitely marked; (5) *vegetation* is less rich and luxuriant than in Torrid Zone, but here the more useful grains and woods flourish; (6) *animals* most common are domesticated; fur-bearing animals are found; (7) *inhabitants*—whites—in the van of civilization.

(*c*) *Frigid Zones*—(1) extremely cold; (2) long, intensely cold *winter*, the sun never being seen for several weeks; (3) short, hot *summer*, the sun never setting for several weeks; (4) *vegetation* is stunted and scanty; (5) *animals*—the chief fur-bearing animals; (6) *inhabitants*—hardy races of fishers and hunters.

4. Comparative Areas of Zones.

(*a*) *Torrid*—about 40% of the entire surface of the earth.

(*b*) *Temperate*—each about 26% of the earth's surface.

(*c*) *Frigid*—each about 4% of earth's surface.

CHAPTER X.

LATITUDE, LONGITUDE AND TIME.

1. Latitude and Longitude.

Already in Chapter V., Section 2, we have learned the meaning of the term *degree.* We also saw that there were 90° from the equator to the pole.

Latitude is distance from the equator, measured in degrees on a meridian, either north or south.

Longitude is distance from a prime meridian, measured in degrees on a parallel, either east or west.

Meridians and Parallels of Latitude.

Latitude is measured from the *equator*. Longitude is measured from the *prime* or *first meridian*. In England the prime meridian passes through the Royal Observatory at Greenwich. Formerly other countries fixed prime meridians running through their several capitals; but within recent years the adoption of the meridian of Greenwich has become nearly universal among the governments of the world.

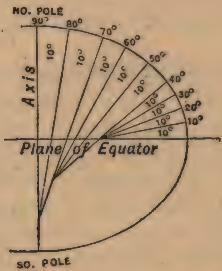
2. Uses of Latitude and Longitude.

If we know the latitude and longitude of a place, we know its exact position upon the earth's surface. We can then find it upon a map or globe as readily as we can find a house from its street and number. The greatest latitude a place can have is 90°, since that is the distance from the equator to the north pole. The greatest longitude a place can have is 180°, or half way around the earth. Hence we have the names latitude (*latus*, broad) and longitude (*longus*, long). The latitude of places on the equator is 0°. The longitude of places on the first meridian is 0°. Hence the latitude and the longitude of the place where the first meridian cuts the equator are each 0°. This is located in the Gulf of Guinea, off the west coast of Africa. Since places on the first meridian have no longitude, and the first meridian runs to the poles, it follows that the poles have no longitude.

3. Length of a Degree of Latitude.

If the earth were a perfect sphere, then all degrees of latitude would be equal in length. But we have found that they are not. See Chapter IV, Section 6, Sub-section (c). Degrees of latitude, then, grow

longer and longer as we approach the poles. The length of a degree of latitude on the equator is 68¾ statute miles. In southern Canada it is 69 miles, and at the pole 69⅜ miles. The figure below shows the reason for this difference.



Degrees Grow Longer (After Todd).

4. Length of a Degree of Longitude.

Measured at the equator the length of a degree of longitude is nearly the same as the length of a degree of latitude. It would be the same were the circumference of the earth at the equator the same as the circumference of the earth drawn through the poles. It has been found to be 69.07 miles at the equator, and, since all the meridians meet at the poles, it follows that a degree of longitude has no length at the poles.

The following table shows the length of a degree of longitude for every five degrees of latitude in statute miles :

Degree of latitude	*Statute miles*	*Degree of latitude*	*Statute miles*
0	69.07	50	44.35
5	68.81	55	39.58
10	67.95	60	34.53
15	65.65	65	29.15
20	64.84	70	23.60
25	62.53	75	17.86
30	59.75	80	11.98
35	56.51	85	6.00
40	52.85	90	.00
45	48.78		

5. How to Find the Latitude of a Place.

(*a*) By means of the sextant find the elevation of the pole star above the horizon. This gives the latitude at once.

(*b*) By means of the sextant find the elevation of the sun above the horizon at noon. From a Nautical Almanac find the declination (distance from the equator) of the sun for that day. If the sun is north of the equator, and the observer in the northern hemisphere, subtract this declination from the sun's elevation, and it will give the height of the sun if the sun were at the equator. Subtract this from 90°, and the remainder is the latitude. If the sun is south of the equator its declination must be added to its observed elevation.

6. How to Find the Longitude of a Place.

(*a*) By means of the sextant mark the time when the sun ceases to rise any higher in the heavens. It is then *apparent* noon. Add or subtract the *equation of time* (the number of minutes the sun is too fast or

too slow; see Chapter VI., Section 3) as found in the Nautical Almanac, and the true or *mean* noon is found. Compare this local time with the time of Greenwich, as found from the ship's chronometer, and by reducing the difference of time to degrees, the longitude is found.

The earth turns 360° in 24 hours, or 1° in $\frac{1}{15}$ hour=4 minutes. That is, a difference of four minutes in time is equivalent to a difference of one degree of longitude.

(*b*) This is an unsafe way of determining longitude, because all depends upon the accuracy of the chronometer. Therefore, the navigator prefers to depend upon the moon. The Nautical Almanac gives, for three years ahead, the distance of the moon from the principal fixed stars which lie along its path, at every hour (Greenwich time) of the night The sailor then determines with his sextant the moon's distance from a certain fixed star, and then, by reference to his almanac, finds the corresponding Greenwich time. By comparing this with his local time, and reducing the difference to degrees, he has his longitude, as before.

7. Time.

(*a*) *Sidereal* time has been fully discussed. (See Chapter VI., Section 3). This is the only absolutely correct time. Astronomical clocks are regulated to keep sidereal time.

(*b*) *Solar* time has also been fully discussed in Chapter VI, Section 3. *Mean* Solar time is kept by our ordinary clocks. A *Sun-Dial* gives the apparent time, which may be readily changed to mean time by

adding or subtracting the number of minutes the sun is too fast or too slow, as shown in the almanac.

(*c*) *Standard* time has been adopted as a matter of convenience. When each place kept its own local time, the annoyance in travelling from place to place was very great. Therefore, in November, 1883, it was decided to establish a standard of time by which railroad trains should run and all ordinary affairs be regulated.

Time all over the World when it is Noon at Greenwich (after Todd).

By this arrangement the North American continent is divided into five sections or belts, approximately 15 degrees of longitude in width, so that the time of each varies from those adjacent to it by exactly one hour. Commencing at the east, these divisions keep Colonial Time, or the time of the 60th meridian; Eastern Time, or the time of the 75th meridian; Central Time, or the time of the 90th meridian; Mountain Time, or the time of the 105th meridian;

Pacific Time, or the time of the 120th meridian. This facilitates matters very much. All that is necessary in travelling is to change your watch one hour when passing from one of these divisions into another, setting it ahead when travelling east, and turning it back when travelling west.

8. The Calendar.

There are two calendars in use at the present day. Russia and Greece still employ the Julian Calendar. All other modern nations have adopted the Gregorian Calendar. The history and differences of these calendars are as follows:

(*a*) *The Julian Calendar* is named after Julius Cæsar, who, B.C. 46, reformed the calendar by the aid of Sosigenes, an Egyptian astronomer. Sosigenes knew the true year was composed of about 365¼ days, so Cæsar decreed that three successive years of 365 days should be followed by a year of 366 days perpetually. This would have needed no correction, but for the fact that this Julian year was 11.2 minutes too long. This accumulated year by year, until in 1582 the error amounted to ten days. In that year the vernal equinox occurred on the 11th of March instead of the 21st.

(*b*) *The Gregorian Calendar*, which was adopted by England in the year 1752, is named after Pope Gregory. He reformed the Julian Calendar by dropping 10 days and ordering that three leap year days be omitted in every four centuries. Thus, although every year not marking the close of a century is a leap year if its number is divisible by four, the centurial years, as 500, 600, 700, 800, are leap years only when exactly divisible by 400.

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